

Labeling Through Scale Using Hierarchies of Thinned Road Networks for Design of *The National Map* of the United States

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Abstract. A sample road network is incrementally thinned with 34 steps using the Thin Road Network tool in ArcGIS® for topographic mapping through scales from 1:24,000 to 1:1,000,000 to evaluate procedures for use in *The National Map* of the United States. Density partitions that preserve local density for urban areas are combined with geometrically increasing scale ranges and calculations based on the Radical Law to select a reduced set of 12 ladderized thinnings. These levels are also used to prioritize road labeling, so more important roads are labeled before over minor roads with less network connectivity. Each scale range uses four thinning levels from the set of 12, with the least thinned adding more local roads in the dense partition, the most thinned level producing roads for the sparse partition, and labeling prioritized with the assistance of two intermediate thinning levels.

Keywords: feature elimination, generalization, map design, multiscale mapping, road labeling, thin road network

1. Introduction

This paper reports on progress in generalization and selective feature removal for roads in the transportation base map layer that enables competent mapping through scales ranging from 1:24,000 to 1:1,000,000. Thinning methods are applied to road features and road labels for *The National Map* of the United States, served by the United States Geological Survey (USGS). Roads are thinned adaptively, which removes features using their

hierarchy within categories and network connectivity, yet preserves characteristic urban/rural local density patterns that can be lost through simple category removals. For example, most U.S. roads are in the local category, but completely removing this category in response to urban road pattern congestion at smaller scales leaves some rural areas devoid of roads. The paper also reports progress on combining multiple levels of road thinning to improve the quality of road label placement (Brewer et al. 2012, in press).

2. Background

Road network generalization is a topic of recent interest. Recognizing the advantages of two network thinning approaches, Li & Zhou (2012) used a stroke-based approach (Thomson & Richardson 1999) in combination with a mesh-density approach (Chen et al. 2009) to thin road networks while maintaining areal patterns. Benz & Weibel (2013) extended this approach. Road thinning operations may be enabled or enhanced through road network or block structure (Jiang & Claramunt 2004, Touya 2010, Gülsen & Gökçöz 2011).

Li & Choi (2002) examined road elimination through scale for topographic mapping of Hong Kong at six scales from 1:1,000 to 1:200,000. They analyzed trends in road elimination related to various road characteristics, and found that road type was the best predictor of road elimination followed by length, number of lanes, number of traffic directions, width, and connectivity at ends of road segments. The U.S. roads data used for *The National Map* does not consistently contain all of these attributes so we cannot build directly from these results.

Gill (1993) and Phillips & Noyes (1977) noted characteristics important to road map reading, which are partly relevant to topographic map design. Phillips & Noyes found that use of straighter names (compared to strongly curved labels), larger sizes, and fewer size categories allowed names to be found faster. Gill found that people performed better on a route planning task if they had visual information about route continuation because they prefer major routes and routes with fewer turns. Participants desired information on built-up areas so they were able to avoid towns, as well as avoiding hilly and winding routes. These results from older projects confirmed that simpler road patterns on smaller-scale displays were those that show and label major routes but also retained urban road densities.

Recent research by Skiles & Howarth (2012) evaluated the advantages of using road signs that include simplified maps showing basic topological relationships among nearby towns and points of interest with the connecting roads in simplified form. Though their research is on outdoor road

signs, it emphasizes the importance of simplified topologically-accurate road patterns for spatial learning.

3. Study Area

Previous work used a sample area near Atlanta, Georgia (USA), to evaluate Esri ArcGIS® 10.1 Thin Road Network tools and refine their use (Brewer et al. 2012, Stanislawski et al. 2012). This paper reports on the next stage in the development of road generalization procedures intended to be useful to the USGS for topographic mapping through scale. It reports on results for a sample area surrounding Des Moines, Iowa (USA), which had a 2010 population of about 203,400. The study area is approximately 140 by 155 kilometers (km), with over 33,000 km of roadways (104,516 road segments; *Figure 1*). This area was chosen because it includes a variety of dense and sparse road patterns. It also has varied densities of hydrographic features as well as corresponding flat and hilly terrain, which we are evaluating in related research (Buttenfield et al. 2013).

4. Road Data Processing

4.1. Generalization

Two ArcGIS® generalization tools were used initially, Merge Divided Highways followed by Collapse Road Detail, to remove doubled and small-detail lines. The USGS Best Practices roads dataset used in this study includes many dual carriageways (two parallel lines for divided highways and boulevards) and these were collapsed to single lines using a 27 m tolerance within road classes (*Figure 2a*). Traffic circles and cul-de-sac ends were removed using a 75 m tolerance (*Figure 2b*), though the Collapse Road Detail tool functioned less reliably for removing small turn lanes. These generalization tools were run on the 1:24,000 (24K) data and the resulting road lengths are listed in *Table 1*. They reduced the total road length by 882 km (from 33,178 to 32,296 km).

These road details being generalized were useful for road display at large map scales but interfered with Thin Road Network processing at longer itinerary lengths. They seemed to provide many alternative routings that caused areas with dual carriageways to persist as high density groupings at smaller scales. The generalized total road length is used as the basis for scale calculations at each thinning level (discussed below; *Figure 3*). The un-generalized roads are shown at 24K-39K and for the dense partition at 40K-59K. The generalized roads are used for the smaller scale ranges. Additional

cartographic generalization such as simplification will likely be useful but was not applied for the results reported here.

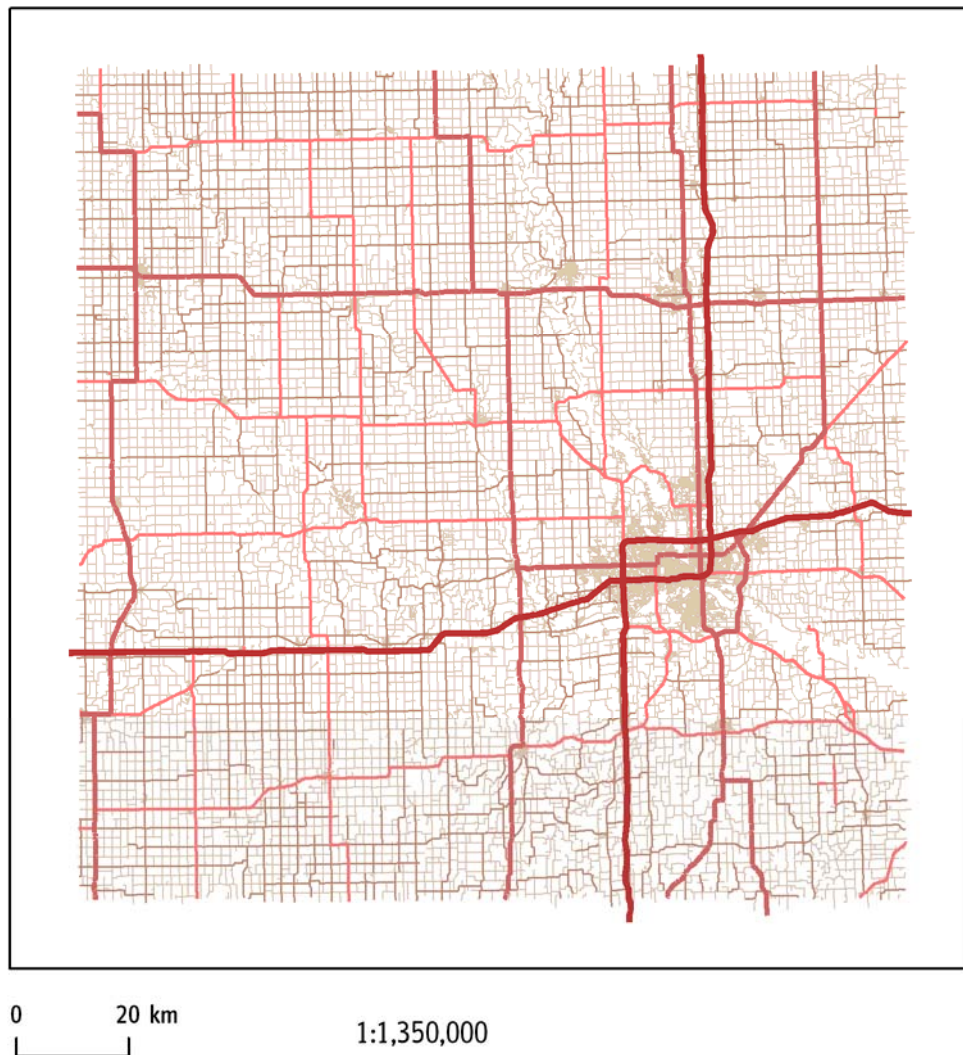


Figure 1. All roads for the Des Moines, Iowa (USA), study area at 1:1,350,000. Wide red roads are interstates and thin light brown roads are local roads.



Figure 2. Examples of a) Merge Divided Highways and b) Collapse Road Detail generalization results at 1:30,000. Magenta roads are merged/collapsed to the lighter blue lines, enlarged in c)—ramps and intersecting roads are repositioned to join the single line resulting from the merge, retaining topology in the network.

Sparse Partition			Dense Partition		
minimum road length (km)	total road length (km)	calculated scale	minimum road length (km)	total road length (km)	calculated scale
all	23,526	24,000	all	8,770	24,000
0.5	22,541	26,143	0.5	7,176	35,850
1	21,769	28,030	1	5,999	51,291
1.5	21,376	29,071	1.5	5,336	64,824
2	21,159	29,670	2	4,893	77,117
2.5	20,985	30,164	2.5	4,635	85,912
3	20,766	30,805	3	4,356	97,299
3.5	20,561	31,421	3.5	4,146	107,403
4	20,291	32,264	4	3,961	117,687
5	19,654	34,386	5	3,604	142,103
6	17,616	42,806	6	3,222	177,847
7	15,592	54,639	7	2,930	214,977
8	14,474	63,406	8	2,631	266,697
9	13,582	72,004	9	2,366	329,804
10	12,339	87,251	10	2,212	377,125
11	11,350	103,112	11	2,133	405,711
12	10,456	121,496	12	2,007	458,068
13	9,723	140,524	13	1,931	495,061
14	9,259	154,931	14	1,825	554,137
15	8,831	170,325	15	1,696	641,865
16	8,200	197,571	16	1,539	779,536
17	7,747	221,351	17	1,473	850,589
18	7,199	256,295	18	1,414	923,610
19	6,651	300,260	19	1,364	991,518
20	6,159	350,213	20	1,335	1,036,015
21	5,644	417,040	21	1,300	1,092,805
22	5,398	455,860	22	1,269	1,146,093
23	5,173	496,331	23	1,244	1,193,702
24	4,772	583,318	24	1,212	1,256,296
25	4,535	646,017	25	1,147	1,404,144
26	4,144	773,384	26	1,089	1,556,726
27	3,867	888,105	27	1,053	1,664,896
28	3,697	971,914	28	1,048	1,681,819
29	3,580	1,036,571	29	1,048	1,681,819
30	3,434	1,126,133	30	1,043	1,696,029

Table 1. Road lengths after generalization (using ArcGIS® Merge Divided Highways and Collapse Road Detail tools) and with laddered minimum-length processing using the Thin Road Network tool.

4.2. Road Thinning

We next processed the roads using the Thin Road Network tool in a ladder fashion, incrementing by 0.5 km minimum length up to 4 km and then by 1 km increments to a 30 km minimum length, producing 34 levels (described here as thinning levels). A chosen minimum length parameterizes Thin Road Network geoprocessing, which makes calculations based on how many itineraries having lengths approximately twice this minimum parameter would travel along each road segment. *Table 1* shows the resulting total lengths of roads that remain after each successive thinning for each density partition. For example, the dense partition (right side of *Table 1*) starts with 8770 km, and is first thinned using a 0.5 km minimum road length to produce 7176 km of roads. Thinning these resulting roads with a 1 km minimum length produces a 5999 km network, and so on until the 30 km minimum length increment produces a road network reduced to a total of 1043 km.

Table 1 also shows the scale at which the density partition is calculated to be suitable for display for each thinned road network. For example, when thinning to 4 km minimum length, the sparse partition (left) is suitable for display at about 1:32,000 scale and the dense partition is suited to 1:118,000. These scales are markedly different, and our recommended procedures revolve around taking advantage of these differences for an objective approach to retaining differential densities across the map that portray variation in human land use. Using a single thinning level across the entire study area, which includes multiple land use types, homogenizes the appearance of the road network. As a comparison, *Figure 3a* shows all roads at 1:225,000 and *Figure 3b* shows only the 7 km minimum road length thinning for the entire area (7 km for the dense partition only is shown at this scale in a later figure).

The calculated scales for each thinning level listed in *Table 1* are produced by inverting a variant of the Radical Law that uses total length rather than number of features (Töpfer & Pillewizer 1966; Brewer et al. 2012, in press). The target scales were each calculated using the total generalized road length at 1:24,000 as the source data (after merging and collapsing) and the resulting road length at each thinning level. The sparse and dense areas of the map were partitioned before beginning the road and label geoprocessing (Stanislawski et al. 2012).

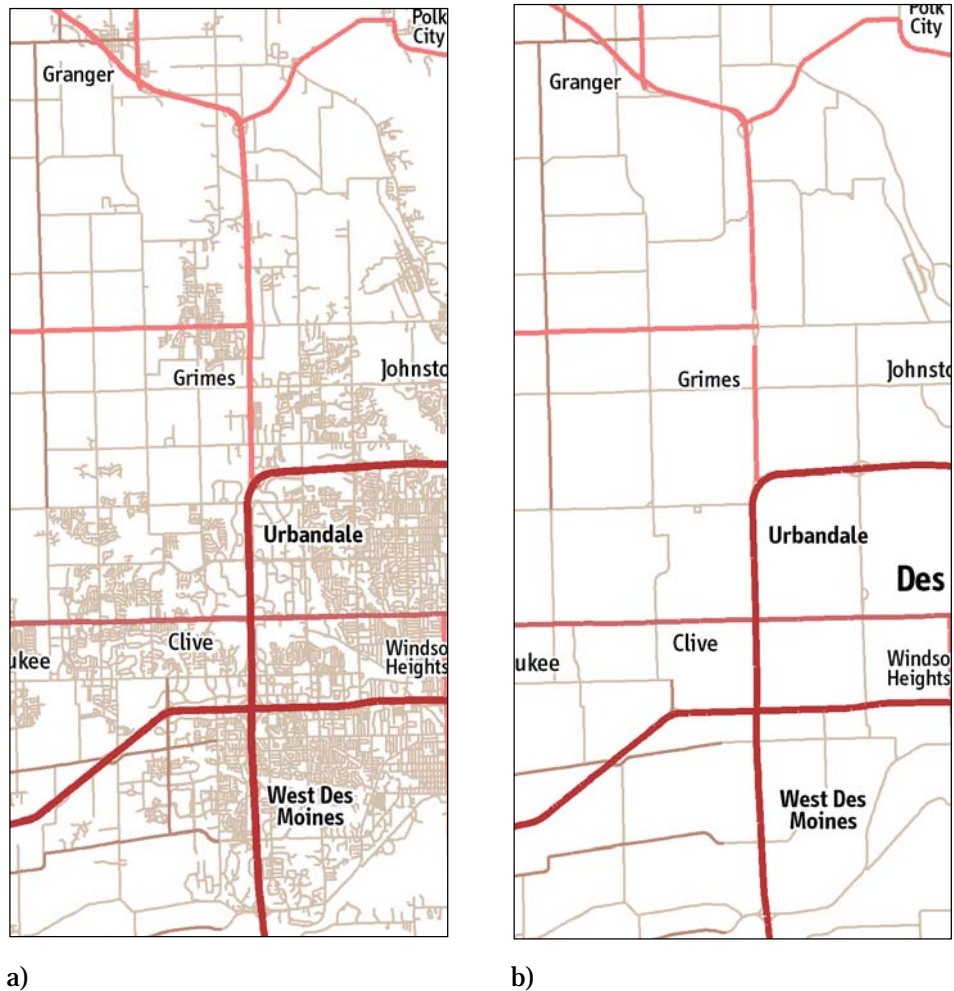


Figure 3. Comparison maps showing a) all roads at 1:225,000 and b) a more homogeneous network resulting from roads thinned using 7 km minimum length for both dense and sparse partitions.

4.3. Scale Ranges

Our goal was to produce mapping through the range of 1:24,000 (24K) to 1:1,000,000 (1M). To make this task more manageable for USGS, we planned a set of nine increasing scale ranges, calculated using a geometric sequence:

- 1M and smaller scales
- 630K to 999K
- 400K to 629K
- 250K to 399K
- 150K to 249K
- 100K to 149K
- 60K to 99K
- 40K to 59K
- 24K to 39K

For each scale range above, we produced one level of detail (LoD) for the road network that is suitable for display through the range. The particular beginning and end points in each range were rounded from the geometric calculation. This general strategy is based on our experience with these data. Small ranges at large scales, and large ranges at small scales, with these approximate magnitudes were being repeatedly selected as we attempted to solve this problem with a variety of road datasets. This decision on range calculation invites later re-evaluation.

4.4. Thinning by Scale Range

The next step was to select a pair of thinning levels for each scale range from the selection of 34 levels in *Table 1*. For example, a 16 km thinning is matched with 198K for the sparse partition and a 7 km thin produced 215K for the dense partition, both scales falling approximately midway through the range 150K to 249K (*Table 2*). Other thinning levels also fall in this scale range (14 to 17 km for sparse; 6 and 7 km for dense). We went through a process of winnowing these choices to maximize the number of shared thinnings across ranges. *Tables 2* and *3* list shared choices among scale ranges for 7 km up to 19 km thinnings. Thus, rather than running 34 increments of the Thin Road Network tool (which took about eight hours on a standard desktop computer), we are able to instead process only the 12 levels listed across the columns of *Table 3*, offering a substantial reduction in processing time and improved production efficiency.

Figure 4 shows dense and sparse partitions for part of the Des Moines study area (sparse partition areas are light purple). Local roads are light brown; state, county, and U.S. routes are light red; and interstate routes are dark red. The sparse area is thinned with 23 km minimum lengths (500K is in the 400K-629K range), and the brown to red roads are present in both the sparse and dense thinnings. The blue roads are those selectively added by the 12 km thinning used for the dense partition only to provide a sense of greater density in the urban area without the clutter of using all roads (*Figure 3a*).

scale range	minimum length - sparse (km)	minimum length - dense (km)
1M+	29	19
630-999K	26	16
400-629K	23	12
250-399K	19	9
150-249K	16	7
100-149K	12	4
60-99K	9	2
40-59K	7	1
24-39K (labels)	0.5	0.5
24-39K	all	all

Table 2. Minimum lengths of thinning levels used for lines and labels in sparse and dense partitions within each scale range.

		Minimum length (km)												
		all roads	0.5	1	2	4	7	9	12	16	19	23	27	29
scale range														
1M+											roads; label class 1	label class 2	label class 3	roads and labels
630-999K											roads; label class 1	label class 2	label class 3	roads and labels
400-629K										roads; label class 1	label class 2	label class 3	roads and labels	
250-399K									roads; label class 1	label class 2	label class 3	roads and labels		
150-249K								roads; label class 1	label class 2	label class 3	roads and labels			
100-149K						roads; label class 1	label class 2	label class 3	roads and labels					
60-99K					roads; label class 1	label class 2	label class 3	roads and labels						
40-59K				roads; label class 1	label class 2	label class 3	roads and labels							
24-39K	dense & sparse roads	dense label class 1; all sparse labels	label class 2	label class 3										

Enlarged row:

roads; label class 1	label class 2	label class 3	roads and labels
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Table 3. Four thinning levels were used for each scale range: three greens for dense partition (to left along a row) and light purple for sparse partition (right). All road lines are shown at the largest scale (beige)

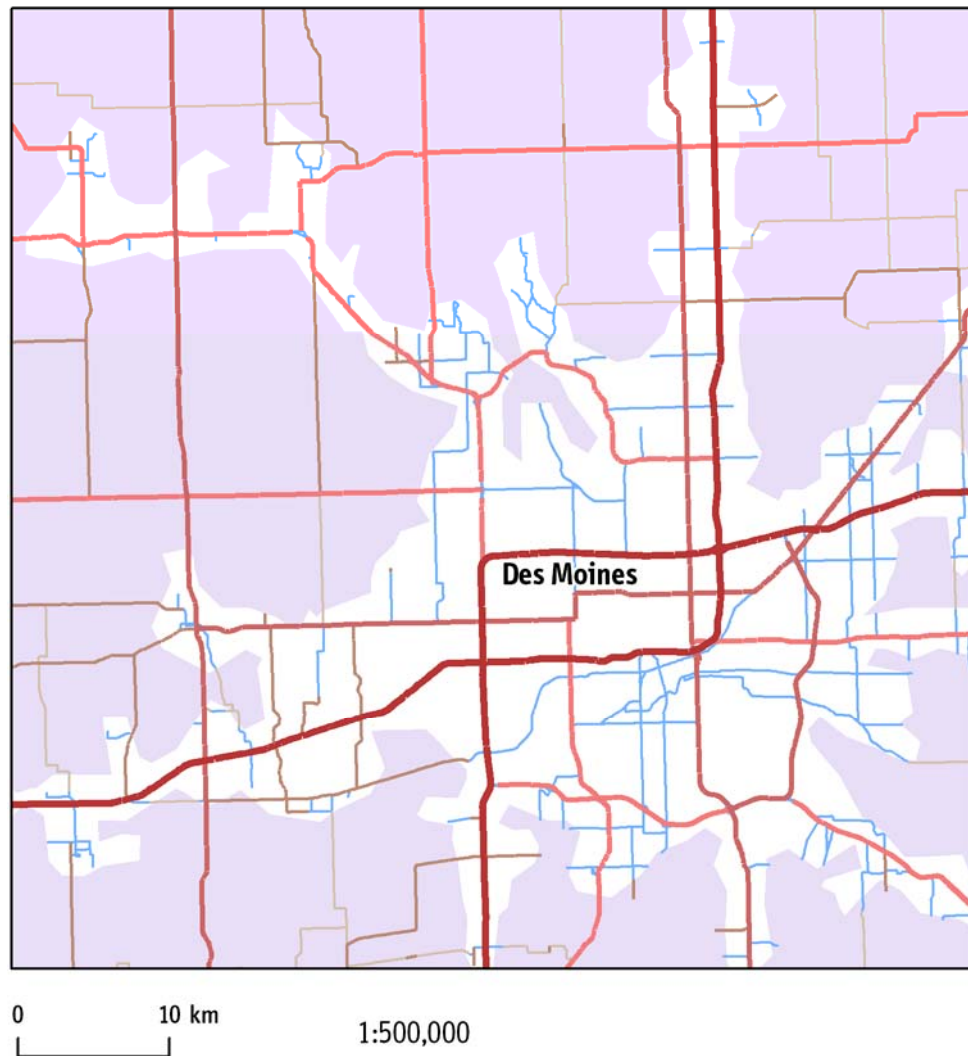


Figure 4. Partitions for a portion of the Des Moines study area (sparse partition areas are in light purple) at 1:500,000. Blue roads are those added to the dense partition by using a shorter minimum length with the Thin Road Network tool (12 km thinning). Reddish and brown roads are in both partitions (23 km thinning).

4.5. Labeling Using Thinning

We labeled local roads using a series of thinning levels (columns; *Table 3*) from the twelve-step series used across all scale ranges (rows). Dense roads were the least thinned (all were shown in the 24-39K range, *Figure 5a*) and label placement for the dense partition was prioritized using three thinning levels (label classes 1, 2, 3 with green tints). Sparse roads and labels were produced using the same thinning level (purple tint in *Table 3*), and these were one level higher from those used for the dense partition within each scale range. Continuing with the 150K-249K scale range as an example (*Figure 5c*), dense partition roads were thinned using a 7 km minimum length and three road classes at 7, 9, and 12 km were used to prioritize label placement. All roads in the sparse partition were labeled using the 16 km thinning level.

This pattern across four levels was maintained through all scale ranges (*Table 3*). It is the reason the 0.5 km thinning was added, so it could be used to reduce the likelihood that small roads were labeled before more important ones for the 24K to 39K scale range. This strategy is intended to put labels on the more important roads within the local roads category for each scale range.

Figure 5 shows the thinned road network results with the dense and sparse partitions combined on single maps through a range of example scales. Dangling road segments along partition boundaries were removed manually for these figures, with that process being automated for upcoming work. It is important to note that these maps will eventually have other labels for features such as hydrography, points of interest, populated places, and emergency services, so smartly prioritizing road label density is as much a challenge as reducing road density. Likewise, the final maps will also include more road labels as we process all names associated with a line—shield-labeled roads often have names in addition to number designations. And many road segments have multiple route numbers, not shown in these draft maps through scale in *Figure 5*.

5. Concluding Comments

Appropriate reduction in road network density for small-scale mapping can be automated if guidelines for thinning are structured in advance. These guidelines for successive road network thinning, however, should be generated concomitantly with density partitioning, because using a single level of density or detail reduction across a dataset results in unrepresentative homogenization of road density, obscuring land use and morphological patterns. We have shown that a systematic reduction of density can be achie-

ved through a relatively wide range of scales. We have also systematized label prioritization through scale. Future work will involve the application of these guidelines to other datasets with different road network patterns. We will also evaluate label hierarchies within the road classes.

Acknowledgements

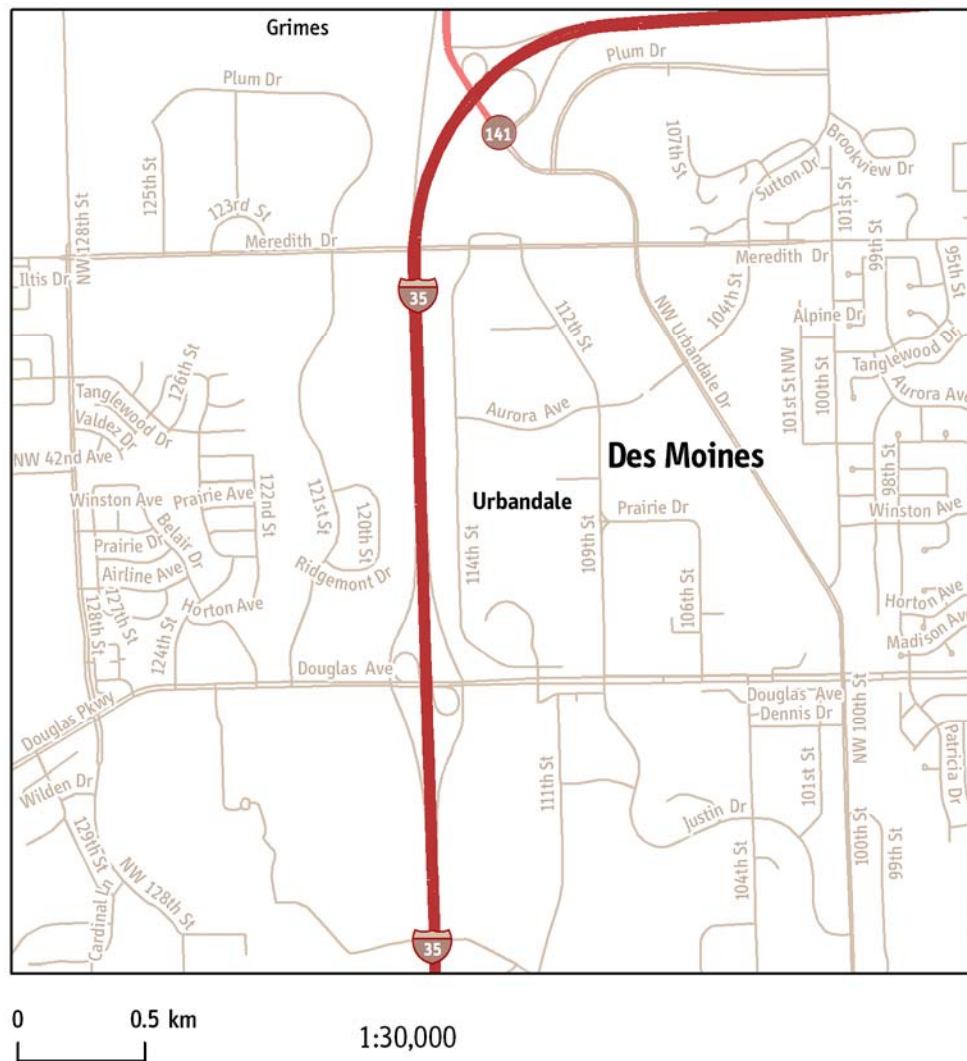
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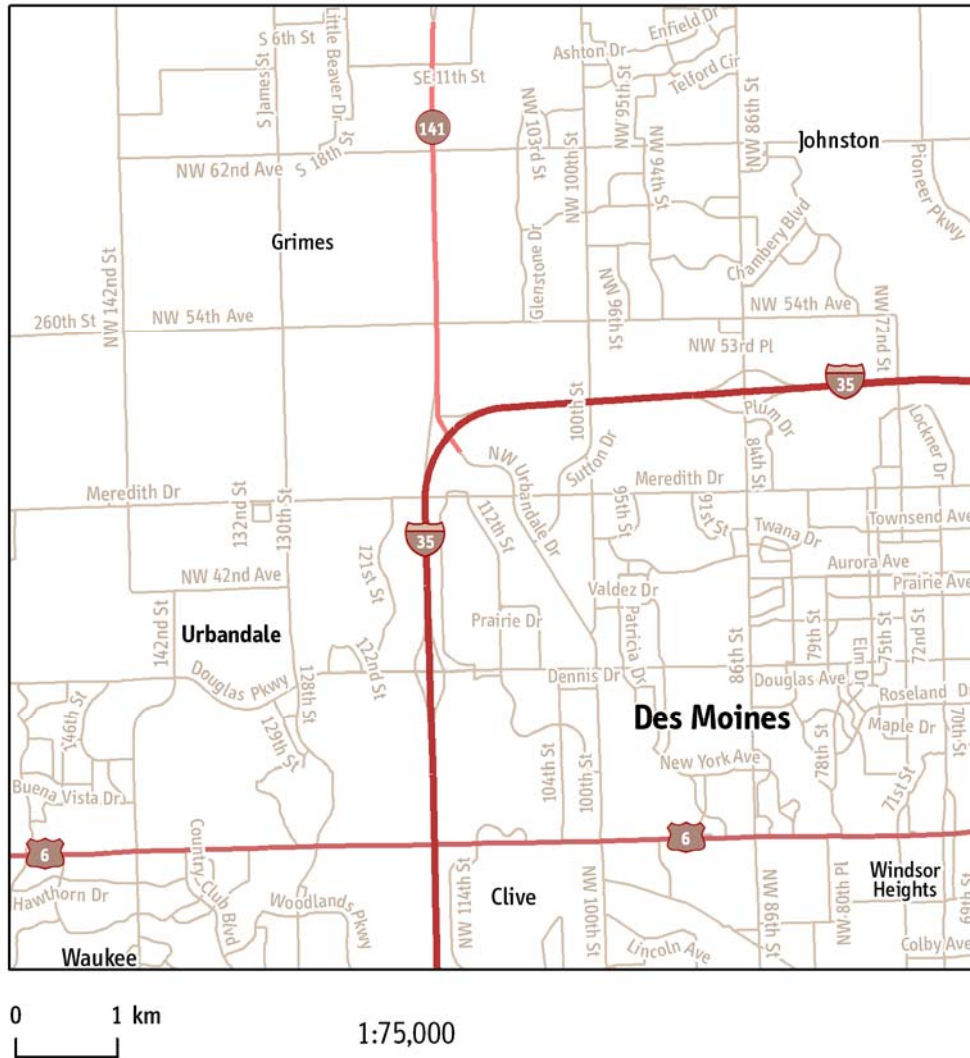
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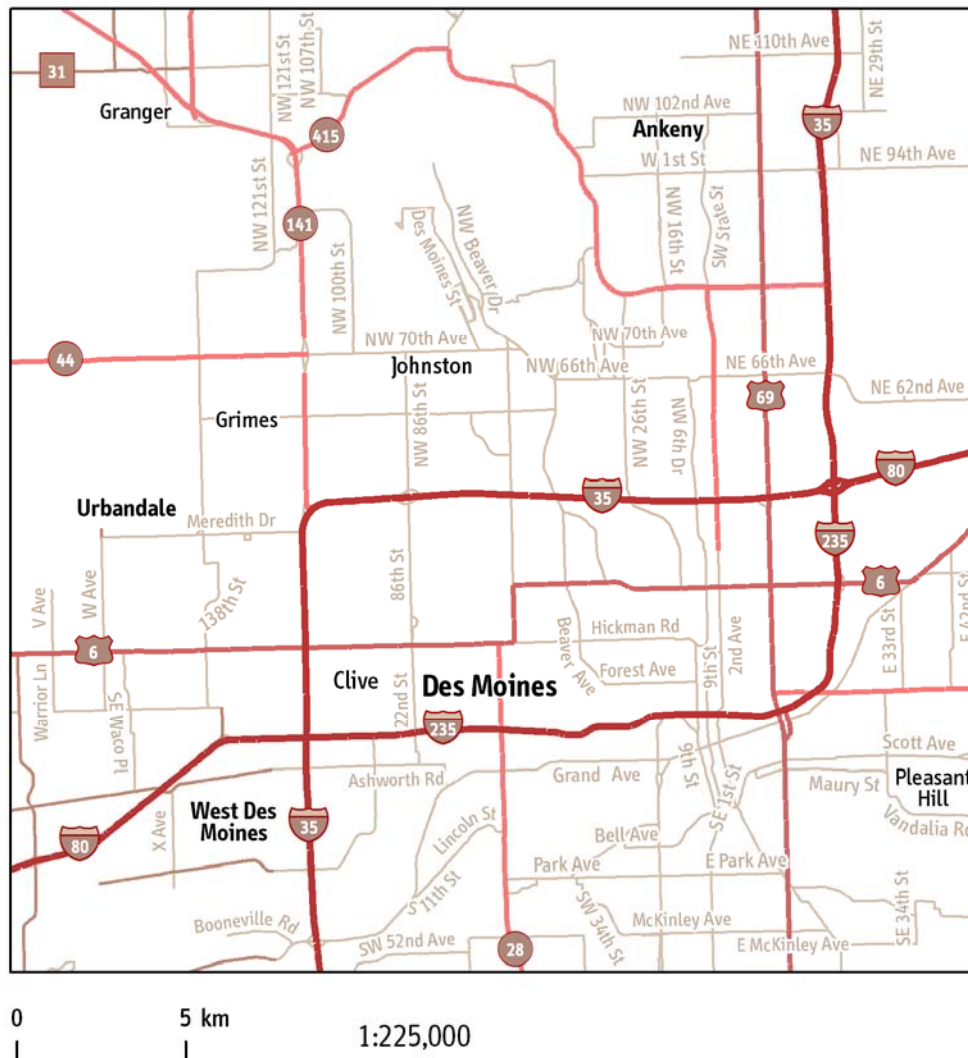
Figure 5. Example scale series: a) 1:30,000; b) 1:75,000; c) 1:225,000; d) 1:500,000; and e) 1:1,000,000. These maps are thinned and labeled according to *Tables 2 and 3*.



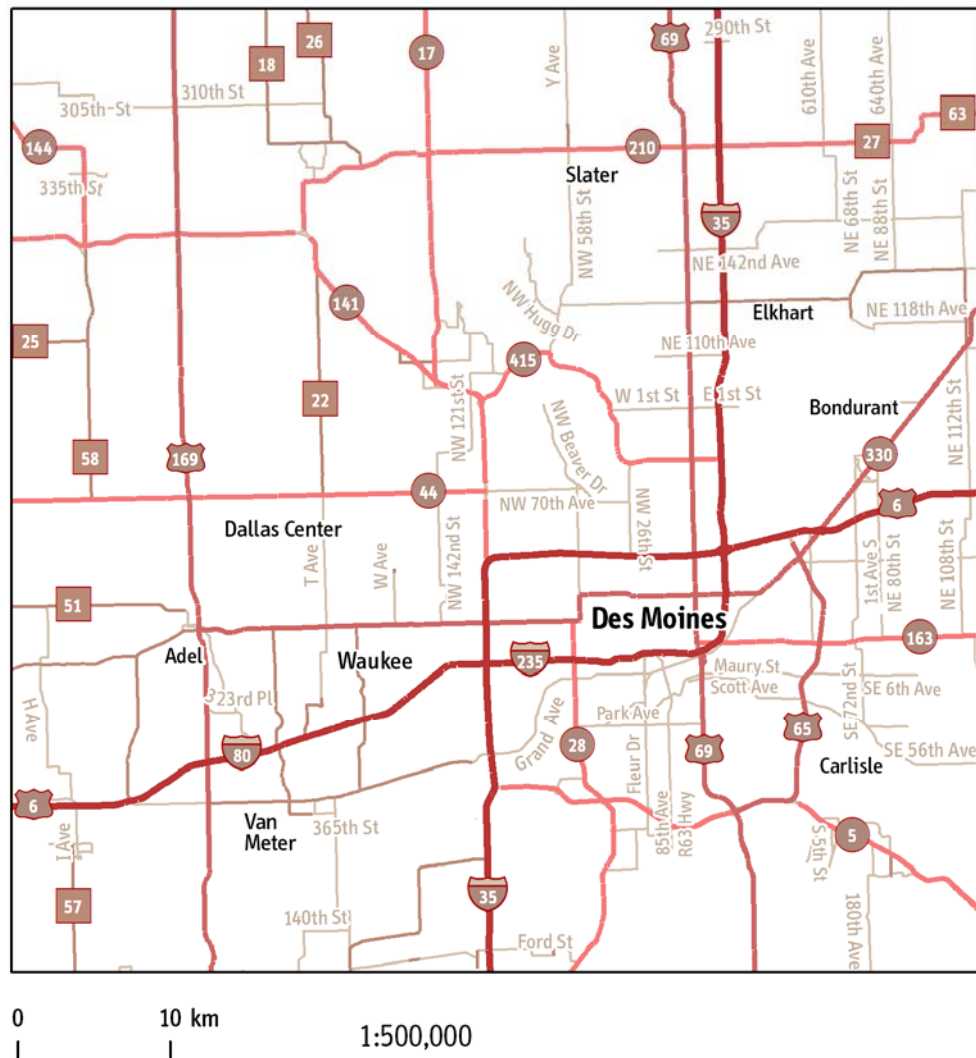
6a) All roads; labels thinned using 0.5 to 2 km minimum lengths.



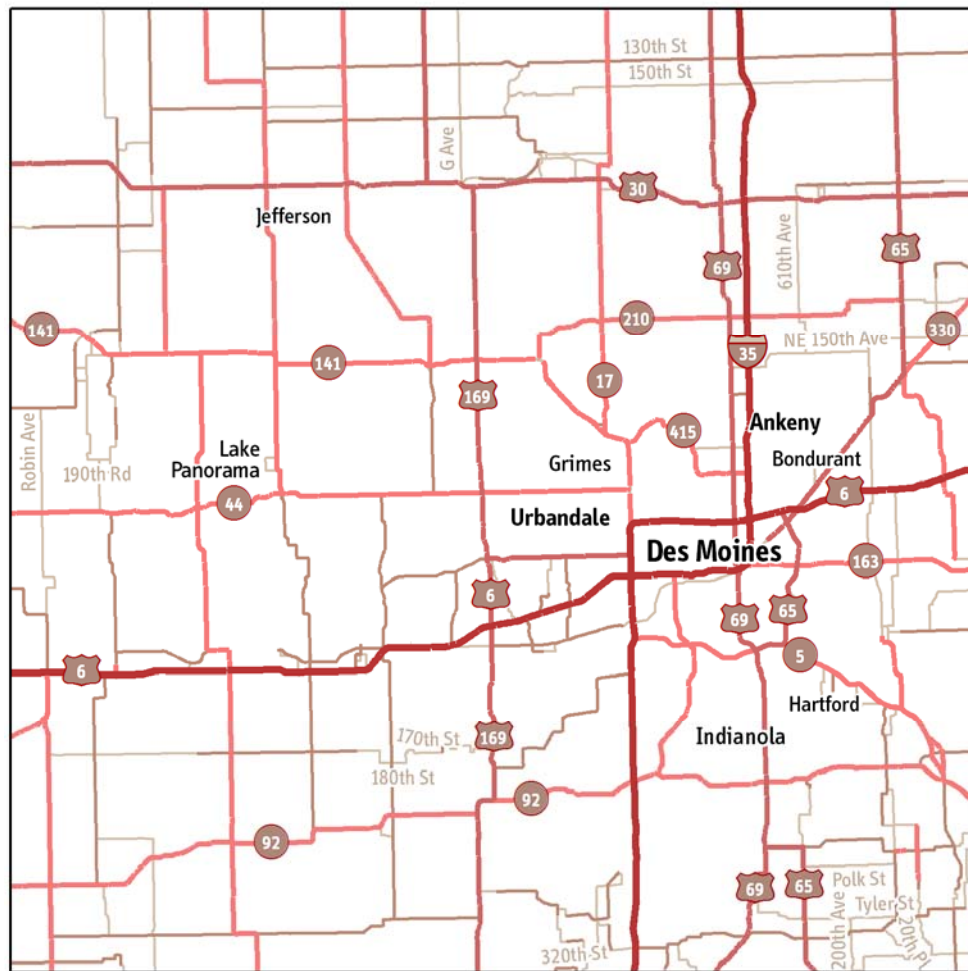
6b) Roads and labels thinned using 2 to 9 km minimum lengths.



5c) Roads and labels thinned using 7 to 16 km minimum lengths.



5d) Roads and labels thinned using 12 to 23 km minimum lengths.



0 20 km 1:1,000,000

5e) Roads and labels thinned using 19 to 29 km minimum lengths.